

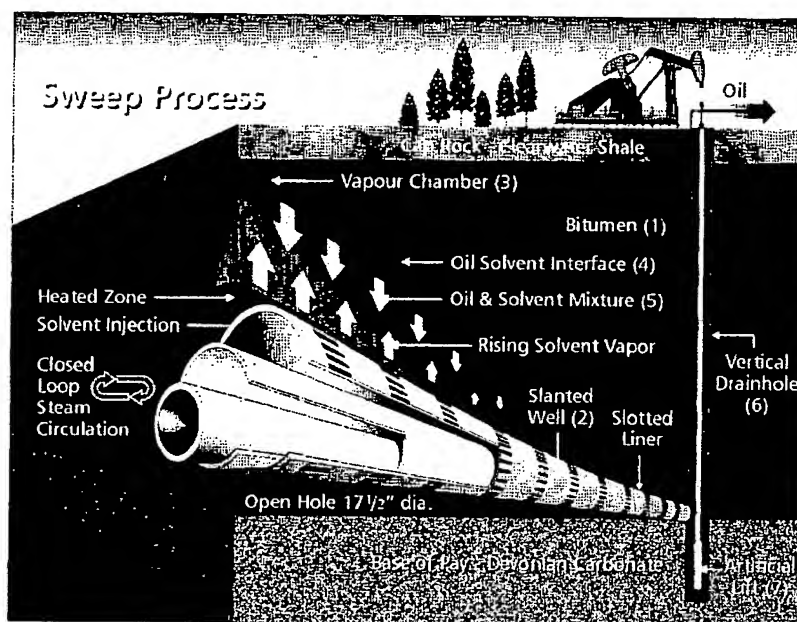


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(54) **PROCEDE D'EXTRACTION AMELIORE, DANS LES PUITES  
INCLINES, POUR LA RECUPERATION D'HUILE LOURDE ET  
DE BITUME AU MOYEN DE CHALEUR ET DE SOLVANTS**  
(54) **SLANTED WELL ENHANCED EXTRACTION PROCESS FOR  
THE RECOVERY OF HEAVY OIL AND BITUMEN USING  
HEAT AND SOLVENT**



(57) A technique for the in-situ recovery of petroleum hydrocarbons from an underground formation uses a combination of heat and vaporized solvents comprising lighter hydrocarbons. Liquid solvent is injected through a substantially slanted well, placed near the base of the reservoir, and is vaporized in-situ by applying heat through an indirect heating system placed inside the slanted well. Hot solvent vapor rises inside the reservoir, contacts the cold viscous hydrocarbons, condenses, dissolves and diffuses into the hydrocarbon in the reservoir. As a result, the viscous hydrocarbon is diluted to a lower viscosity fluid, which drains to the slanted well and is thereafter produced to the surface.

**ABSTRACT OF THE DISCLOSURE**

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A technique for the in-situ recovery of petroleum hydrocarbons from an underground formation uses a combination of heat and vaporized solvents comprising lighter hydrocarbons. Liquid solvent is injected through a substantially slanted well, placed near the base of the reservoir, and is vaporized in-situ by applying heat through an indirect heating system placed inside the slanted well. Hot solvent vapor rises inside the reservoir, contacts the cold viscous hydrocarbons, condenses, dissolves and diffuses into the hydrocarbon in the reservoir. As a result, the viscous hydrocarbon is diluted to a lower viscosity fluid, which drains to the slanted well and is thereafter produced to the surface.

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**APPLICATION FOR PATENT**  
**SLANTED WELL ENHANCED EXTRACTION**  
**PROCESS FOR THE RECOVERY OF HEAVY**  
**OIL AND BITUMEN USING HEAT AND SOLVENT**

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**Field of the Invention**

This invention relates to a process for the recovery of high viscosity hydrocarbon resources from subterranean hydrocarbon bearing reservoirs with the application of heat and solvent using a special well configuration.

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**Background of the Invention**

Highly viscous hydrocarbons, known as heavy oil and bitumen, exist inside the fine pores of the subterranean porous formation called reservoir. To extract the hydrocarbons from these reservoirs, the hydrocarbons have to be mobilized inside the porous formation and allowed to flow to holes drilled inside the formation called wells. The mobilized hydrocarbon is then brought to the surface and processed for its end use. The efficient extraction of these hydrocarbons out of the porous formation is the objective of this disclosure.

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Although there is an enormous amount of resources available in the form of heavy oil and bitumen, their high viscosity prevents its flow in the formation. Depending on the reservoir temperatures and the type of resources the mobility of the fluid varies. In large areas of the underground Alberta oil sand the temperature is in the range of 10oC and the hydrocarbons in the formation would be a few million times more viscous than water at ambient conditions. Under this reservoir condition the hydrocarbon has a thick, semi-solid appearance and is substantially immobile even outside the formation. In the heavy oil reservoirs the mobility is usually higher than that at the Athabasca oil sand reservoirs, however, the conventional recovery techniques have been unsuccessful in recovering these resources. The high viscosity of these resources demands special recovery techniques.

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Certain prior art publications of interest in this field are noted as follows:

#### References

- Butler, R.M., "Method for Continuously Producing Viscous Hydrocarbons by Gravity Drainage while Injecting Heated Fluid", Canadian Patent 1,130,201, August 24, 1982,  
5 US patent 4,344,485, Aug 17, 1982.
- Das, S.K., "In Situ Recovery of Heavy Oil and Bitumen Using Vaporized Hydrocarbon Solvents", Ph.D. Thesis, University of Calgary, 1995.
- Nzekwu, B.I., Sametz, P.D. and Pelensky, P.J., "Single Horizontal Wellbore Gravity Drainage Assisted Steam Flooding Process", US patent 5,626,193, May 6, 1977.
- 10 Anderson, D.J., "Method of Recovering Viscous Petroleum From an Underground Formation", US patent 4,037,658, July 26, 1977.
- Dewell, R.R., "In Situ Extraction of Asphaltic Sands by Counter-current Hydrocarbon Vapor", US patent 4,067,391, Jan 10, 1978.
- Sanchez, J.M., "Process/Apparatus for the In Situ Extraction of Viscous Oil by Gravity Action Using Steam Plus Solvent Vapor", US patent 5,148,869, Sep 22, 1992.
- 15 Jensen, E.M., Uhrich, K.D. and Hassan, D.J., "Single Well Vapor Extraction Process", US patent 5,771,973, June 30, 1998.

Mobility of these hydrocarbons increases with increase in temperature. Based on this  
20 principle various thermal recovery techniques have been applied for the recovery of these hydrocarbons. One of the more successful processes, the steam assisted gravity drainage (SAGD), Canadian Patent 1,130,201, 1982 noted above, a steam based process using a pair of horizontal wells drilled into the reservoir and placed one vertically above the other, has been used successfully for the recovery of these high viscosity resources. In  
25 this process steam is injected in the upper well of the well pair. The injected steam condenses inside the reservoir and heats the formation and hydrocarbons. The hot mobilized oil and the condensed water drains to the lower horizontal well by gravity. This hot fluid is produced to the surface by natural or artificial lift. Heat transfer over a huge surface area along the edge of the steam chamber formed during the process and the  
30 gravity head are the key factors in achieving a high extraction rate in this process. Various other well configurations have also been attempted.

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Although the SAGD process has met with commendable success, it suffers from the inherent disadvantages of higher energy requirement, environmental pollution (emission from steam generation), high capital costs for the surface facilities for water treatment, etc.

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Viscosity of heavy oil and bitumen may also be reduced by injection of solvent into the reservoir. This forms the theoretical basis for any solvent recovery process. One of the prior art processes (named VAPEX) injects vaporized hydrocarbon solvent into the reservoir through an injector and the diluted oil, due to its lower viscosity, drains to a production well (Das, 1995). This process has so far been investigated in laboratory experiments. In the solvent-based extraction processes, the solvent recovery at the surface is crucial for the economic success of the process and requires significant capital investment.

15 A combination of heat and solvent has been visualized as a solution to this problem in our pending Canadian application Serial No. 2,281,276 filed August 31, 1999. A near well bore heating mechanism in the production well is used to revaporize the solvent and the solvent vapor condenses at the solvent-bitumen interface inside the reservoir. This solvent action dilutes the oil that drains to the horizontal producer. Thus the same solvent  
20 is effectively recycled and utilized inside the reservoir. A small amount of make up solvent is injected through a horizontal producer. Production through these horizontal wells, especially in case of two or three phase flow situation, is quite complicated and it is difficult to maintain a gravity stable drainage process along the entire length (~1000 m) of the production well. Much of the time this may end up in solvent vapor bypassing  
25 (as it happens in the steam process, SAGD).

The above techniques use a pair or more of horizontal wells for the process. There are prior techniques in which a single well is used for both injection of the heated fluid or solvent and production of the mobilized oil. Nzekwu et al. (US patent 5626193)  
30 presented a single wellbore SAGD process, which was applied in the field operation. Results indicated a limited growth of the steam chamber and primarily the near well bore

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heating phenomenon in this process.

Anderson presented a proposal (US patent 4037658) for creating a horizontal passage in the formation by delivering heat through a tubular carrying hot fluid. A drive fluid  
5 (steam) is injected into the formation through one end of the heated passage to promote movement of the viscous hydrocarbon along the passage, external to heat delivery tubular. The displaced fluid is produced through a recovery shaft at the other end of the passage.

10 Dewell (US patent 4,067,391) proposed a special design of a horizontal conduit for delivering heated hydrocarbon vapor to the formation and the recovery of viscous hydrocarbon. A Plurality of multilaterals is drilled from a vertical shaft to distribute the solvent vapor and recover the hydrocarbon.

15 In another proposal (Sanchez, US patent 5148869) a similar conduit was proposed to be used for simultaneous injection of steam and hydrocarbon solvent vapor into the formation. Thus steam is allowed to heat the reservoir by conductance while hydrocarbon vapor enters the hydrocarbonaceous reservoir fluids. Heated hydrocarbonaceous fluids with dissolved solvent, having a reduced viscosity flow from the reservoir around the  
20 horizontal wellbore.

Jensen et al. (US patent 5771973) presented a proposal in which a tubing string placed inside a horizontal well with raised end (toe) is used for injection of unheated hydrocarbon solvent as saturated vapor. Viscous reservoir hydrocarbon, mobilised due  
25 to dilution by the solvent, drains to the horizontal section of the same well and is produced through a second tubing string.

#### **Summary of the Invention**

Accordingly, the invention in one aspect provides a method for the in-situ recovery of  
30 viscous petroleum hydrocarbons from an underground formation comprising:  
(a) providing a slanted well within the formation, (b) providing solvents in the formation

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above the slanted well which are capable of dissolving in and diluting the hydrocarbons to reduce the viscosity and promote drainage of said hydrocarbons toward the slanted well, with a vapour chamber being created above the slanted well in the hydrocarbon-depleted formations resulting from said drainage, (c) maintaining a hot zone adjacent to or at the slanted well to vaporize solvents contained in the downwardly draining hydrocarbons prior to or upon their entry into the slanted well such that the vaporized solvents move upwardly through the vapour chamber in a continuing manner to again contact said hydrocarbons in the formations at the boundaries of the vapour chamber to promote the continued dilution and drainage of the hydrocarbons toward said slanted well whereby a substantial portion of the solvents are recycled within the formation, and wherein (d) said slanted well is sloped downwardly from a first point to a second point sufficiently that the downwardly draining hydrocarbons entering said well pass along said well by gravity from the first point to the second point; and (e) producing to the surface the hydrocarbons which have reached the second point of the slanted well.

The method thus provides for the in-situ recovery of viscous petroleum hydrocarbons from an underground formation using a combination of heat and vaporized solvents comprising lighter hydrocarbons. Liquid solvent is injected through the substantially slanted well, placed near the base of the reservoir, and is vaporized in situ by applying heat through an indirect heating system placed inside the slanted well. Hot solvent vapor rises inside the reservoir, contacts the cold viscous hydrocarbons, condenses, dissolves and diffuses into the hydrocarbon in the reservoir. As a result, the viscous hydrocarbon is diluted to a lower viscosity fluid, which drains to the slanted well. Although the primary effect of viscosity reduction is achieved due to the solvent dilution, the increased temperature inside the reservoir also aids the process by causing additional reduction in viscosity. Depending on the solvent composition used there may be some in situ deasphalting and upgrading of the viscous reservoir hydrocarbon. This may also cause some reduction in viscosity.

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The hot/diluted oil in one embodiment is drained into the slanted well, flows to the toe, and is collected in a vertical drain hole drilled at the toe of the slanted well. The vertical well is equipped with artificial lift to produce the oil to the surface facility for treatment. The process is named SWEEP (Slanted Well Enhanced Extraction Process). More than  
5 one slanted well may drain to a single vertical well. This may reduce the number of vertical wells required and reduce the capital and operating costs. Alternatively several slanted wells may drain to a single horizontal well drilled at the base of the reservoir. The hot bitumen from this horizontal well is produced to the surface using an artificial lift.

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The slanted well, drilled down-dip from the heel is typically completed with a closed loop circulation heating arrangement. Steam or any other hot fluid is circulated through a pair of concentric tubings of the closed loop circulation heating system to transmit heat to the reservoir fluid without contacting the reservoir with steam (termed as indirect  
15 heating). Due to the indirect nature of the heating system, the return condensed water is not contaminated by reservoir fluids and does not require elaborate surface treatment for the purpose of recycling or disposal, thereby significantly reducing the surface facilities. This also eliminates the operating pressure and temperature constraints, which are dictated by the fracture pressure of the formation. A high pressure and temperature  
20 heating fluid system may be used inside the closed loop system without subjecting the reservoir to the same high pressure.

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The purpose of this energy supply into the reservoir is to boil off the solvent dissolved in the diluted oil. This vaporized, previously injected solvent along with the makeup  
amount of solvent moves to the unextracted formation, contacts the viscous hydrocarbon and continues the extraction process. This process is repeated in a continuous fashion and the solvent component is recycled again and again inside the reservoir. This in situ solvent recycle reduces the size of the surface treatment facility and the solvent recovery unit. The capital and operating costs are also reduced significantly. Several of the slanted  
30 wells may drain to a single vertical/horizontal well reducing the overall number of well and pads requirement. Also, in a solvent-based gravity drainage extraction process the



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solvent has to be present in the vapor phase in the extraction chamber. The in situ supply of heat provides a superior way of maintaining the vapor phase in the reservoir compared to injection of vaporized solvent at the surface, which may condense on its way to the reservoir.

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It should be noted that when a mixed solvent such as naphtha is used, only the lighter hydrocarbon components are vaporized and refluxed into the reservoir. The heavier fractions of the solvent mixture remain in the liquid phase and act as the diluent aiding in the lifting process. This also reduces the requirement of diluent blending at the surface, necessary for bringing down the viscosity of the crude oil to the pipeline specification.

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In a variation of the process a single well may be drilled from a surface location that goes down to the hydrocarbon reservoir, travels the desired length inside the reservoir with a desired dip and comes out of the ground at another surface location. The segment of the well inside the reservoir is completed with a slotted liner or wire-wrapped screen. The closed loop heating system is placed inside the slanted section of the well through one of the vertical shafts. The oil is produced using an artificial lift placed in the other shaft of the well. This reduces the uncertainty of intersecting the vertical drain hole or the producer with a slanted well drilled from another pad location.

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The closed loop indirect heating system may be replaced by any other heat energy supply system such as an electrical or electromagnetic induction heating (EMI) system. In EMI heating system electric current is passed through a set of magnetic coils, attached to the outside of the tubing inside the slanted well. This induces heating of the liner of the slanted well. The liquid solvent, injected in the annular region, is vaporized by the heat energy delivered by this process. This heat energy also boils off the dissolved solvent from the oil drained to the slanted well.

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A variation of the process utilizing electrical/EMI heating system may use an electrical submersible pump (ESP) attached to the toe of the tubing inside the slanted well, to lift the oil to the surface through the tubing. The exterior of the same tubing is used to place

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the electromagnetic element along the slanted segment of the well for induction heating. With this configuration it is possible to eliminate the requirement of the vertical well.

5 In another variation of the process the slanted section is drilled up-dip from the heel. The well is completed in a very similar manner as in a down-dip well. In this configuration the diluted and hot oil flows along the length of the slanted well to the heel section of the well which is then produced to the surface by using an artificial lift. Along the length of the slanted well the dissolved solvent vaporizes and refluxes back into the reservoir. The make up solvent is either injected near the toe of the well or at the middle of the slant  
10 section through a tubing, concentric to the closed loop heating system.

The overall purpose of the process is to sufficiently saturate the bitumen with solvent in the colder section of the reservoir, such that its viscosity is reduced enough to allow the oil to flow by gravity drainage to the production well. The energy supplied in the slanted  
15 well further reduces the viscosity of the oil through heating, and re-vaporize the dissolved solvent in the oil. This causes a "reboil" effect in the reservoir, as the re-vaporized solvent rises and combines with the injected solvent vapor to continue the extraction of the viscous hydrocarbon. The heated oil is produced to surface free of the lighter fractions of the dissolved solvent, and potentially free of water, which will remain in the reservoir.  
20 As such, this becomes a continuous process for the recovery of heavy oil and bitumen from oil sands using smaller number of wells or replacing a pair of horizontal wells used in the prior arts with one slanted well and one or no vertical well.

A considerable volume of the bitumen resources are present at a depth (~100 m), which  
25 deeper than the mining capability and shallower than the capability of the currently available in situ recovery technologies. Some of the conventional in situ recovery technologies using a pair of horizontal wells may not be applicable in these reservoirs due to the challenges in drilling horizontal wells in the shallow reservoirs. Use of slanted wells in the present invention may be useful for recovering these reserves. Since the heat  
30 transfer fluids do not contact the reservoir directly the pressure of the SWEEP operation can be controlled to a lower range suitable for this shallow reservoir.

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**Brief Description of the Drawings**

Figure 1 is a diagram illustrating the operation of the SWEEP process;

Figure 2 is a schematic cross-section through a formation showing details of one embodiment of the well configuration;

5 Figure 2A shows a finned section of external tubing;

Figures 3 and 3A are schematic elevation and plan views of the process using multiple slanted well for each vertical well;

Figure 4 is a schematic of the SWEEP process using electrical / EMI heating;

Figure 5 is a schematic of the process using electrical/EMI heating and ESP;

10 Figure 6 is a schematic of the process using a single up-dip slanted well;

Figure 7 is a schematic of the process using a U-shaped well.

**Detailed Description of Preferred Embodiments**

This invention is a method of in-situ recovery of heavy oil and bitumen, using a  
15 combination of heat and vaporized solvents as explained in Figure 1. Heavy oil and  
bitumen are present in underground reservoir 1, depicted as dark gray color zone in  
Figure 1, in a highly viscous and immobile form. The solvent is injected into the reservoir  
through a slanted well 2. The solvent consists of a combination of hydrocarbon vapors  
containing one or more of methane, ethane, propane, butane, pentane, hexane, heptane,  
20 octane, xylene, toluene, distillate, natural gas condensate, naphtha and all of their  
isomers. The solvent may include one or more of non- hydrocarbon compounds such as  
carbon dioxide, sulfur dioxide, and hydrogen sulfide, including small amounts of  
nitrogen and oxygen. The solvent may be injected either as a vapor, liquid or a vapor-  
liquid mixture and may be vaporized inside the wellbore and the reservoir by the  
25 application of heat.

Heat is injected into the reservoir through the closed loop circulation heating system as  
explained below in detail. The primary purpose of the heat injection is to boil the solvent  
out of the diluted oil accumulated at the slanted well; the hot oil with minimal solvent is  
30 produced to the surface through the production well. The hot solvent vapor moves  
generally upwardly through the vapor chamber 3 which has developed within the

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formation and condenses at the oil-solvent vapor interface 4, dissolves in the oil and reduces the viscosity; the heat transfer at the interface also aids in viscosity reduction due to increase in temperature. The hot and diluted mobile oil 5 drains by gravity downwardly through the formation to the slanted well near the base of the reservoir, enters the well via suitable openings in the well liner and flows along the dip of the well to a vertical drain hole 6. Along its journey to the production end the dissolved solvent is vaporized from the mobilized oil; it goes back into the reservoir via the vapor chamber 3 and again dissolves and leaches the reservoir oil in the colder section at the interface 4 of the reservoir. Since, the same solvent is recycled and reused again and again inside the reservoir, only a small amount of makeup solvent is injected to fill up the void space created inside the reservoir due to oil production. This significantly reduces the surface operations, offering an efficient method for the recovery of highly viscous hydrocarbons with greatly reduced emissions. The heated mobilized oil is withdrawn continuously through the vertical well 6 and is produced to the surface, either by natural lift or using any artificial lift 7.

The solvent is selected on the basis of the reservoir temperature and operating pressure. The proposed solvent should stay in the vapor phase under the conditions inside the vapor chamber. However, it should condense at the solvent vapor-bitumen interface 4. Around the injector and the producer due to higher temperature the solvent will remain in the vapor phase. However, the reservoir beyond the solvent oil interface 4 will be close to the initial reservoir temperature and the solvent should have enough solubility at the interface. Ideally the solvent composition should be such that at these temperatures and pressures it is in the vapor-liquid region and can split into the liquid and vapor phases in the required proportions.

The first step in solvent selection involves setting an operating pressure. This should be close to the reservoir pressure and obviously should be lower than the fracture pressure of the reservoir. Lower operating pressure ensures confinement of the chamber and maintains the vapor phase. On the other hand a higher operating pressure eliminates the need for artificial lift and increases the solubility of the lighter components of the solvent

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vapor in the bitumen.

5 In the second step the range of temperature achievable inside the reservoir due to the indirect heating is estimated. The third step involves pre screening of the possible solvent composition through PVT calculations with the help of an equation of state. Any PVT software package may be used for this purpose. Solvent compositions in vapor-liquid region at the operating pressure and the lower end of the temperature range are short-listed.

10 In the fourth step either PVT measurements should be carried out or the same PVT software package may be used (when the interaction parameters are known / approximated) to estimate the solubility and the corresponding viscosity reduction of these selections at the solvent oil interface conditions. The composition that yields the highest viscosity reduction would be selected. An overall optimization of the operating  
15 pressure, temperature range and the solvent composition should be carried out for the best performance of the process. In a reverse approach, the properties of the available solvent may be used to determine the operating conditions.

20 For example in a reservoir at original temperature of 8 C and 1000 kPa, if it is established that the near interface temperature would be close to 25 C, pure propane or propane with a small amount of other hydrocarbons may be used as the solvent for the SWEEP process. The near well bore temperature may be in the range of 150-200 C which will be sufficient to boil off all of the dissolved solvent and still the viscosity of the hot oil will be low enough to be lifted using a conventional artificial lift. On the other hand if it is  
25 desirable to operate the process at a lower pressure, naphtha or a condensate may be used to match the operating pressure and temperature. Use of heavier solvents will require a higher temperature near the well bore to vaporize most of the dissolved solvent. Even then some of the heavy components of the solvent mixture may still remain in the liquid phase and act as diluent and help in lifting and transportation of the oil.

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Figure 2 presents the details of the slanted well 8 with the closed loop heating system and the vertical well 9. The slanted well 8 is drilled from the ground surface 10 through the overburden 11 into the reservoir 12 and completed with a casing 13 from surface to the slanted segment and cemented. In the slanted segment the well is completed with either

5 of slotted liners 14, wire mesh wrapped screens, prepacked liners, perforated casing, open hole 15 or any combination of these. The closed loop circulation heating system consists of a pair of concentric tubes placed inside the well and it extends from the surface to the end (toe) 8a of the well completion string or open hole inside the formation containing the viscous hydrocarbon. The external tube 16 of the pair of concentric tubing, may or

10 may not consists of sections of finned tubes 17 of any design along the entire or part of the slanted length, and is closed with a plug at the toe. The inner tube 18 is of a smaller diameter than the external tube, creating an annular space between the two tubings, 16 and 18. Hot fluids including steam is injected through the inner tubing and condensed liquid with or without any vapor returns to the surface through the closed annulus.

15 Alternatively the hot fluid is injected through the annulus of the concentric tubing and the condensed liquid and associated vapor, if any, is produced through the inner tubing. The heat is transmitted from the hot fluid inside the external tubing to the fluid outside the external tubing through the wall of the external tubing without the fluids physically contacting each other and hence the heat transfer process is termed as indirect heating.

20 Solvent is injected into the annular region between the casing 13 and the outer tubing 16 of the closed loop heating system. A perforated tubing, placed inside the entire length of the well, may also be used for solvent injection to ensure the uniform distribution of the solvent along the entire slanted length of the well.

25 The heat transfer process is limited by the amount of heat transfer area (the wall 16 of the external tubing). Preliminary calculation shows that only 50 m<sup>3</sup>/d (condensed water equivalent) of steam could be used in a closed loop circulation heating system of 1000 m length of the slanted segment, and 1600 m total length with a external and internal tubing diameter 5 1/4" and 3 1/2" respectively. Depending on the extraction rate in SWEEP

30 and the solvent concentration in the diluted oil in the mobilized oil, the amount of heat transfer may not be sufficient to vaporize or "reboil" all or most of the solvent dissolved

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in the oil. The purpose of the fins on the external tubing is to increase the heat transfer area and facilitate the heat transfer process. Addition of the external fins may result in utilization of more than 150 m<sup>3</sup>/d (condensed water equivalent) of steam inside the same closed loop system increasing the heat input into the reservoir.

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An optional insulating tubing string 19 (Fig. 2) may be placed between the inner and outer tubing of the closed loop heating system to prevent heat transfer between the injected and return fluid in the vertical and deviated sections of the well prior to the liner 14 installation. The annular region between the insulating tubing 19 and the inner steam injection tubing 18 may be filled with a gas e.g., methane, nitrogen etc. Alternatively conventional insulated tubing may be used in the vertical and deviated sections of the steam injection tubing 18.

The vertical well 9 is drilled from the ground surface to the base of the reservoir to create a sump 20 at the bottom. The vertical well is cased and cemented up to the base of the formation to prevent any communication with the solvent vapor chamber. The slanted well 8 is drilled afterwards to hit this vertical drain hole as closely as possible. This ensures drainage of the mobilized fluid into the vertical wellbore. An artificial lift (e.g. pump) 21 is installed in this vertical well 9 to lift the recovered oil to the surface.

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In a typical SWEEP operation the slanted well length may be in the range of 200 to 1000 m with a dip angle between ½ to 10°. Depending on the well length, reservoir and solvent characteristics about 2-50 m<sup>3</sup>/day of solvent will be injected into the slanted well. Steam will be circulated into the closed loop heating system at a rate of 10-100 m<sup>3</sup>/day. Operating pressure inside the reservoir will be slightly higher than the saturation pressure of the lighter fractions of the solvent at the original reservoir temperature. The estimated extraction rate is in the range of 15-100 m<sup>3</sup>/day of bitumen or heavy oil produced.

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Figures 3 and 3A present the schematic of multiple slanted wells 22, 23, 24, 25 and a single vertical well 26 in a bitumen reservoir. Oil draining into the slanted wells flows to the vertical well 26 and is produced by an artificial lift. Similarly a multitude of slanted

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wells may be drilled to intercept a single horizontal drain hole. The horizontal well gathers all oil draining through the slanted wells and is produced to the surface using artificial lift. The dip angle of the slanted wells in the elevation view of Fig. 3 is highly exaggerated. The dip angle is selected on the basis of the required gravity potential to flow the expected liquid volume along the length of the slanted segment. The perforated tubing 14 may be used to distribute the solvent uniformly along the slanted length of the well.

Figure 4 presents the schematic of a variation of the process in which the closed loop heating system is substituted by an alternative source of energy supply to the slanted well. Electromagnetic induction heating coils or electrical heaters 29 are installed inside the slanted segment 8 of the well. These are supplied with electrical power from the surface through insulated or jacketed electrical cables. Depending on the reservoir characteristics and well length about 0.3 to 2 MW of electrical energy will be delivered to the slanted well by this method. The make up amount of solvent is injected into the annulus and vaporized inside the wellbore along with the dissolved solvent. The produced oil drains to the vertical well 9 and the hot oil is produced to the surface using artificial lift 2. A modification of this variation presented in Figure 5 uses an electrical submersible pump (ESP) 30 attached to the tubing string and placed at the toe of the slanted well 31 to pump the oil to the surface. In this modification the vertical well is not required.

Figure 6 presents a single slanted well SWEEP operation in which the slanted segment is drilled up-dip from the heel of the well 31. The well is completed with a closed loop heating system with steam injection 32 and return 33 string. Solvent is injected through another concentric tubing 34. The solvent diluted hot oil drained from the reservoir flows through the well bore from the toe of the well 35 to the heel 31 section. A production tubing 36 is landed in the annular space between the closed loop heating system and the casing 37. An artificial lift system 38 e.g. ESP, rod pump, progressive cavity pump or gas lift is attached to this tubing 36 and is used to withdraw the fluid to the surface. In this option also the vertical drain hole is eliminated. The closed loop heating system in this



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variation may also be eliminated by using an alternative mode of energy supply e.g. electrical or electromagnetic induction heating etc.

5 In another variation of SWEEP, presented in Figure 7, a dual entry U well is drilled from one surface location 39, becomes slanted 40 inside the formation and then drilled upwards to come out to the surface at another surface location 41. The well is cased in the vertical and deviated segment and completed with slotted liner, wire mesh wrapped screens, prepacked liners, perforated casing, open hole or any combination of these 42. The closed loop heating system comprising steam injector tube 43, steam return tube 44 and optional insulating string 45 are installed inside the well through one surface location 10 and extends up to the end of the slanted segment. A production tubing 46 is landed through the second surface location up to the deviated section into the fluid collected in the slanted well bore. An artificial lift 47 attached to this tubing string 46 lifts the oil to the surface.

15 Unlike other proposed methods of using solvent(s) for the extraction of viscous hydrocarbon this process employs both heat and solvent vapors. The specific well configuration and the presence of the closed loop circulation heating system in the present invention eliminates the initial start up phase required in the prior techniques using a pair of horizontal wells. The oil production in the present invention may start 20 from the very beginning of the project. Inside the slanted wellbore the fluid flows along the pressure gradient aided by the gravity head in the slanted segment. This may be compared to the prior art using a pair of horizontal wells, where wellbore pressure losses in the injector imposes a negative pressure gradient on the fluids flowing in the producer. 25 This makes the drainage process gravity unstable and results in the bypassing of steam or solvent. Similarly in a single well based process bypassing of steam and solvent is a serious problem, which is alleviated using the slanted well design in the present invention.

30 The uniqueness of the present invention lies in (a) the requirement of less number of wells or cheaper wells and pad locations, (b) in situ recycling of the solvent reducing

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surface operation, and (c) providing an efficient and economic process for the recovery of heavy oil and bitumen.

5 Preferred embodiments of the invention have been described and illustrated by way of example. Those skilled in the art will realize that various modifications and changes may be made while still remaining within the spirit and scope of the invention. Hence the invention is not to be limited to the embodiments as described but, rather, the invention encompasses the full range of equivalencies as defined by the appended claims.

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**CLAIMS:**

1. A method for the in-situ recovery of viscous petroleum hydrocarbons from an underground formation comprising:
    - (a) providing a slanted well within the formation;
    - 5 (b) providing solvents in the formation above the slanted well which are capable of dissolving in and diluting the hydrocarbons to reduce the viscosity and promote drainage of said hydrocarbons toward the slanted well, with a vapour chamber being created above the slanted well in the hydrocarbon-depleted formations resulting from said drainage;
    - 10 (c) maintaining a hot zone adjacent to or at the slanted well to vaporize solvents contained in the downwardly draining hydrocarbons prior to or upon their entry into the slanted well such that the vaporized solvents move upwardly through the vapour chamber in a continuing manner to again contact said hydrocarbons in the formations at the boundaries of the vapour chamber to promote the continued dilution and drainage of  
15 the hydrocarbons toward said slanted well whereby a substantial portion of the solvents are recycled within the formation; and wherein
    - (d) said slanted well is sloped downwardly from a first point to a second point sufficiently that the downwardly draining hydrocarbons entering said well pass along said well by gravity from the first point to the second point; and
    - 20 (e) producing to the surface the hydrocarbons which have reached the second point of the slanted well.
  2. The method of claim 1 wherein said slanted well is provided with a heating  
25 system providing said hot zone for effecting indirect heating of the formations and enhancing the mobility of the downwardly draining hydrocarbons adjacent thereto.
  3. The method of claim 2 wherein the solvents are injected via the slanted well; the amount of solvents injected during steady-state operation being related to the amount of  
30 solvents lost via the oil which is produced to the surface and the amount of solvent retained inside the formation in the vapour phase and in the diluted residual oil.
-

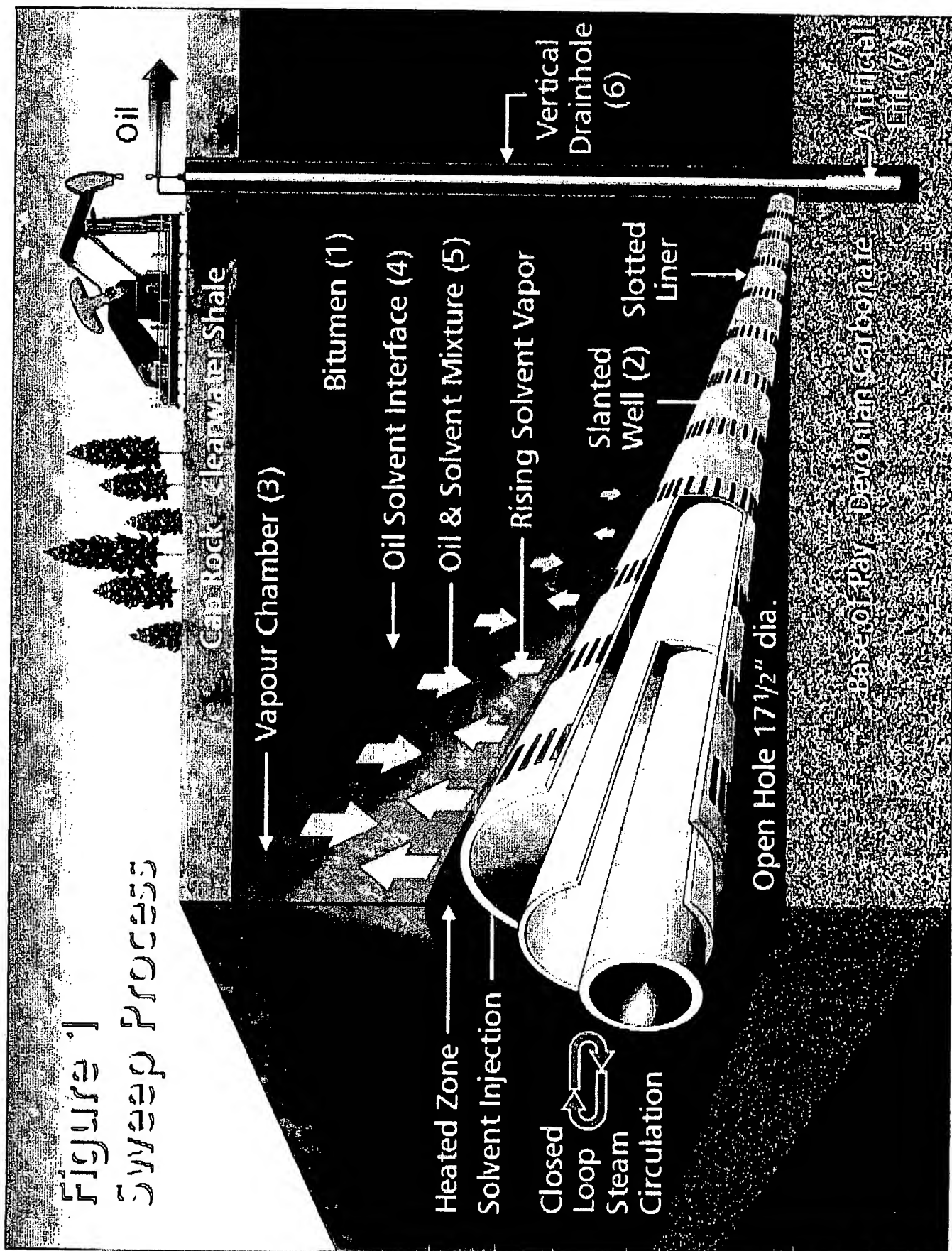
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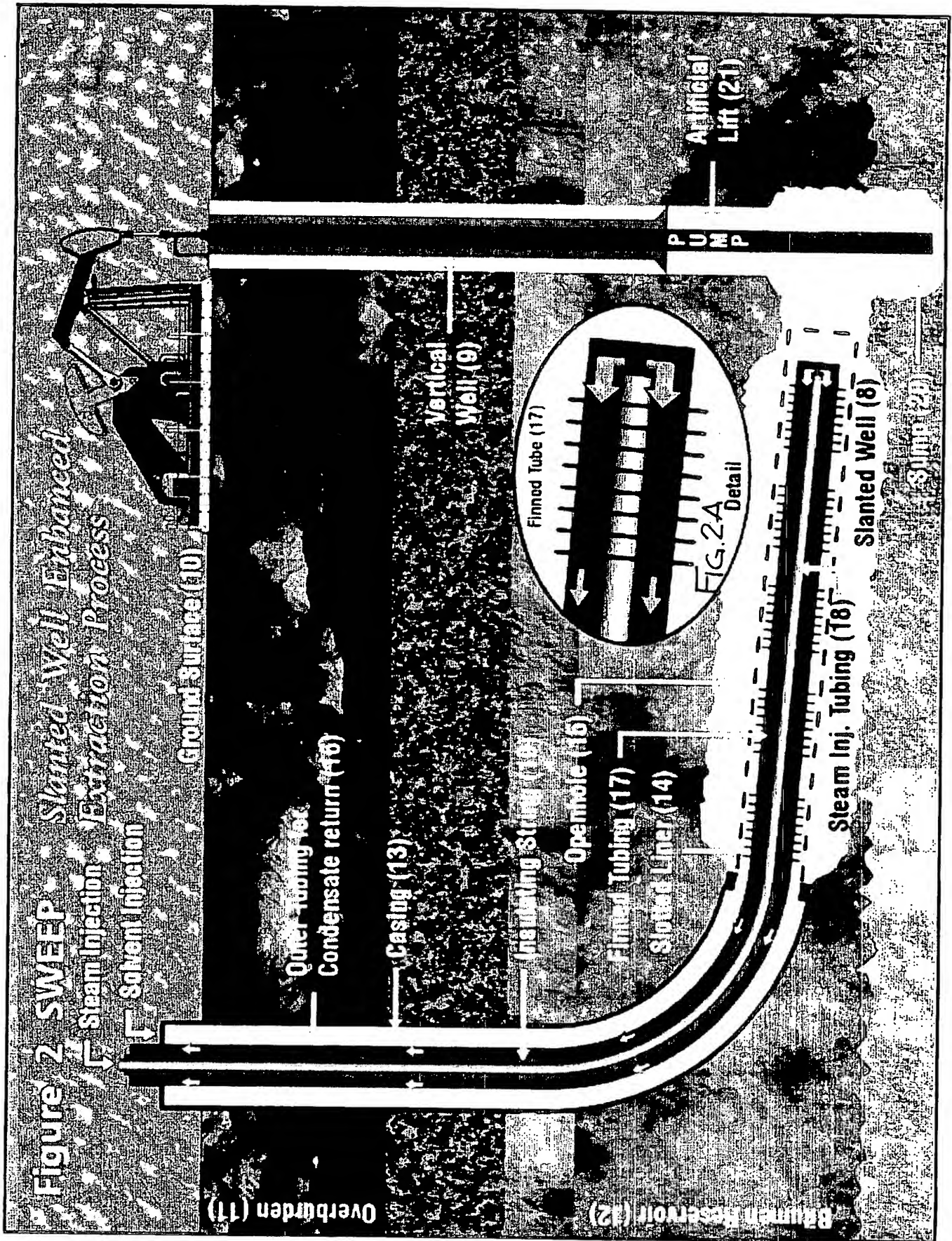
4. The method of claims 2 or 3 wherein said heating system includes a pair of concentric tubes positioned in said well and defining a flow path for heated fluids arranged to effect transfer of heat to the surroundings.
- 5 5. The method of claim 4 wherein the outer one of said concentric tubes is finned to enhance transfer of heat to the surroundings.
6. The method according to any one of claims 1-5 wherein the solvents include hydrocarbons selected from the group consisting of methane, ethane, propane, butane,  
10 pentane, hexane, heptane, octane xylene, toluene, distillate, natural gas condensate naphtha and their isomers.
7. The method according to any one of claims 1-6 wherein the solvents are selected so as to condense and dissolve at an interface with the petroleum hydrocarbons to transfer  
15 heat to said hydrocarbons while diluting and reducing the viscosity of same.
8. The method according to claim 2 wherein the heating is effected by electrical/electromagnetic induction heating coils located within said slanted well.
- 20 9. The method according to any one of the preceding claims wherein the slanted well is completed with one or more of slotted liners, wire mesh wrapped screens, pre-packed liners, perforated casings or combinations thereof.
10. The method according to any one of claims 1-9 wherein a plurality of said slanted  
25 wells are provided each of which is arranged to drain down towards an upright well through which the hydrocarbons are produced to the surface.
11. The method according to any one of claims 1-9 wherein the slanted well comprises an up-dip well with said first point being at the toe end of the well and said  
30 second point being at the heel of the well.
-

-20-

12. The method according to any one of claims 1-9 wherein the slanted well forms a lowermost section of a U-well, said well having upright well sections connected to each of the opposing ends of the slanted well, with a first of said well sections supplying heat and solvents to the slanted section and the hydrocarbons being produced to surface  
5 through the second of the said well sections.
-

Figure 1  
Sweep Process





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# Slanted Well Enhanced Extraction Process (SWEEP)

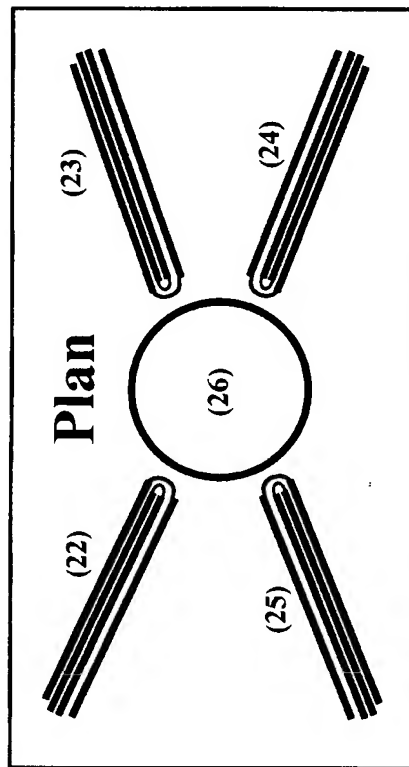


FIG. 3A

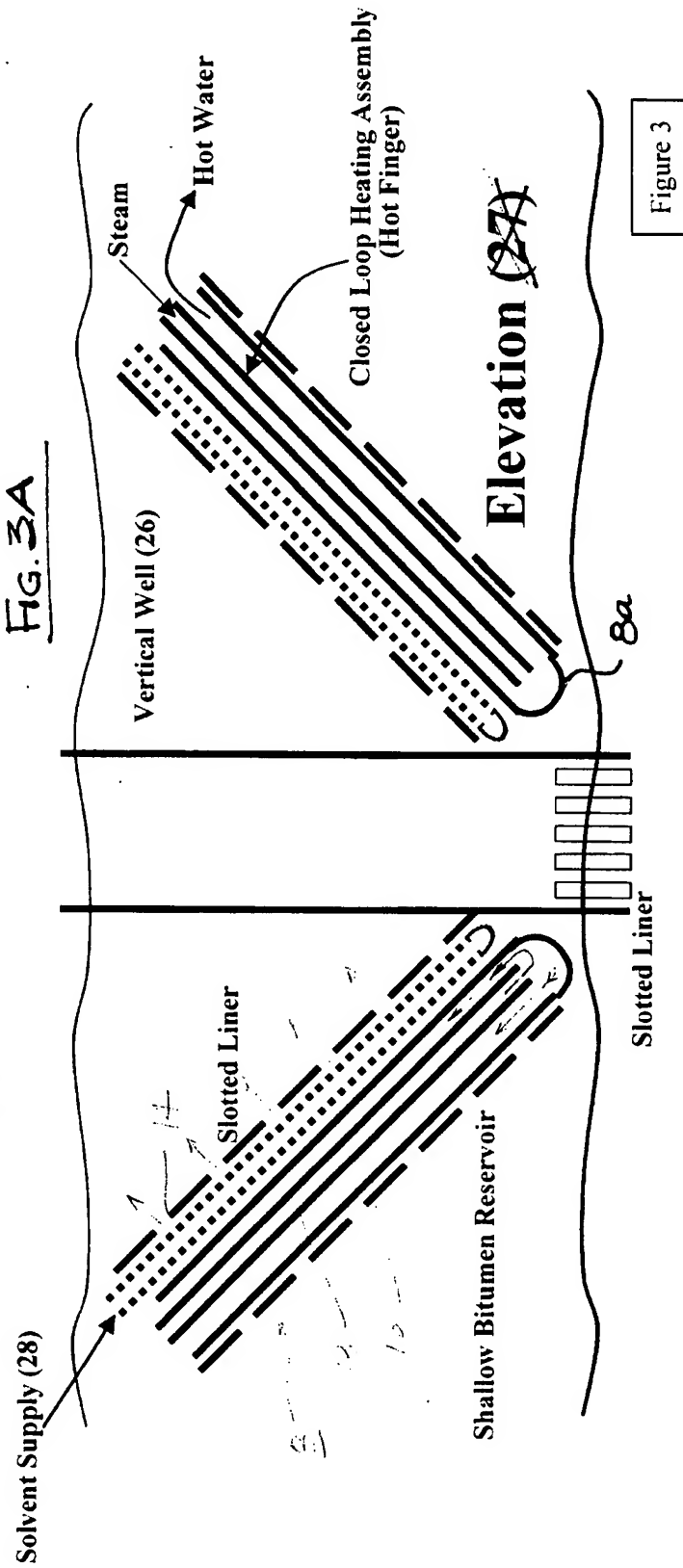


Figure 3



# SWEEP USING ELECTRICAL/EMI HEATING

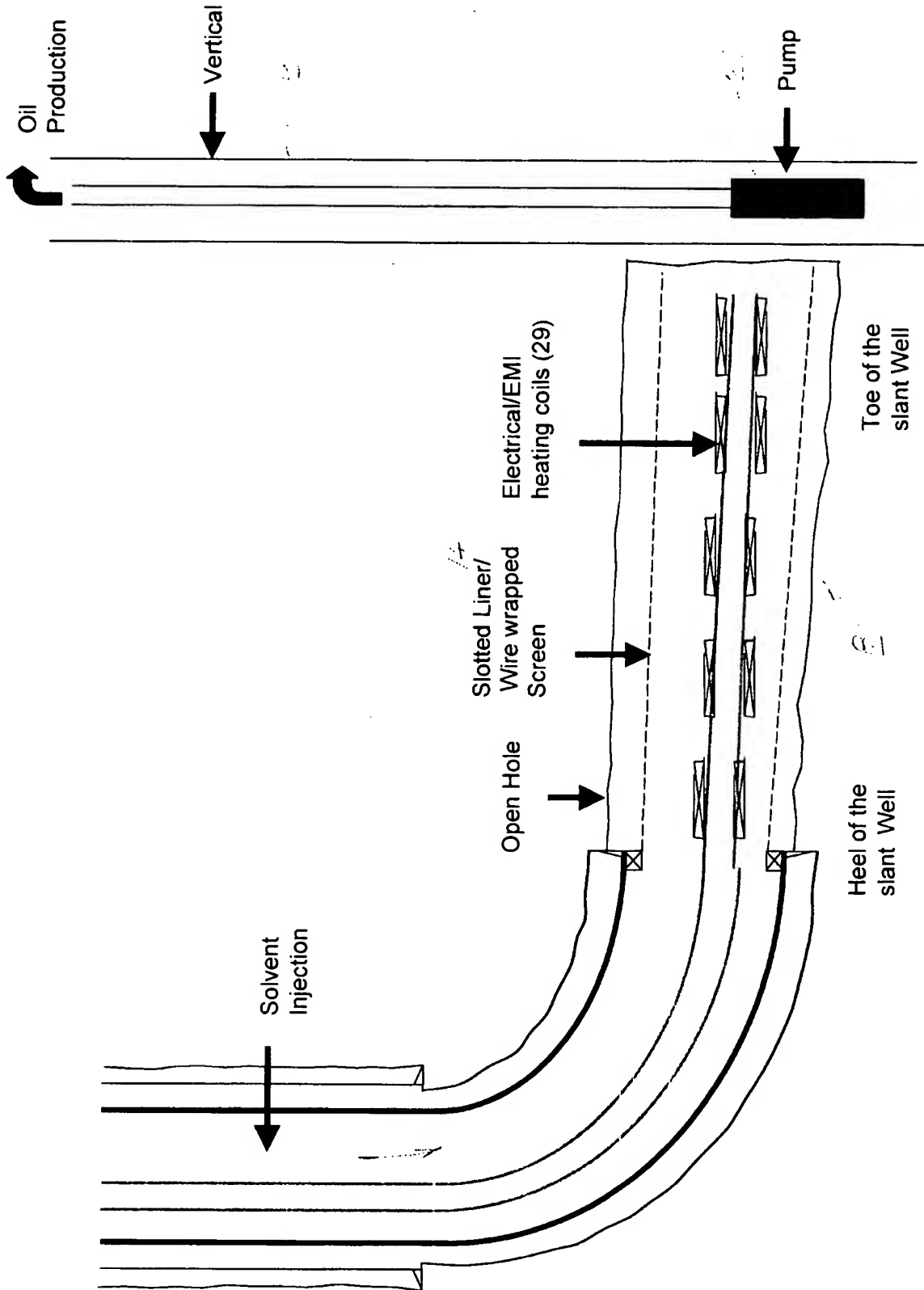


Figure 4

# SWEEP USING ELECTRICAL/EMI HEATING AND ESP

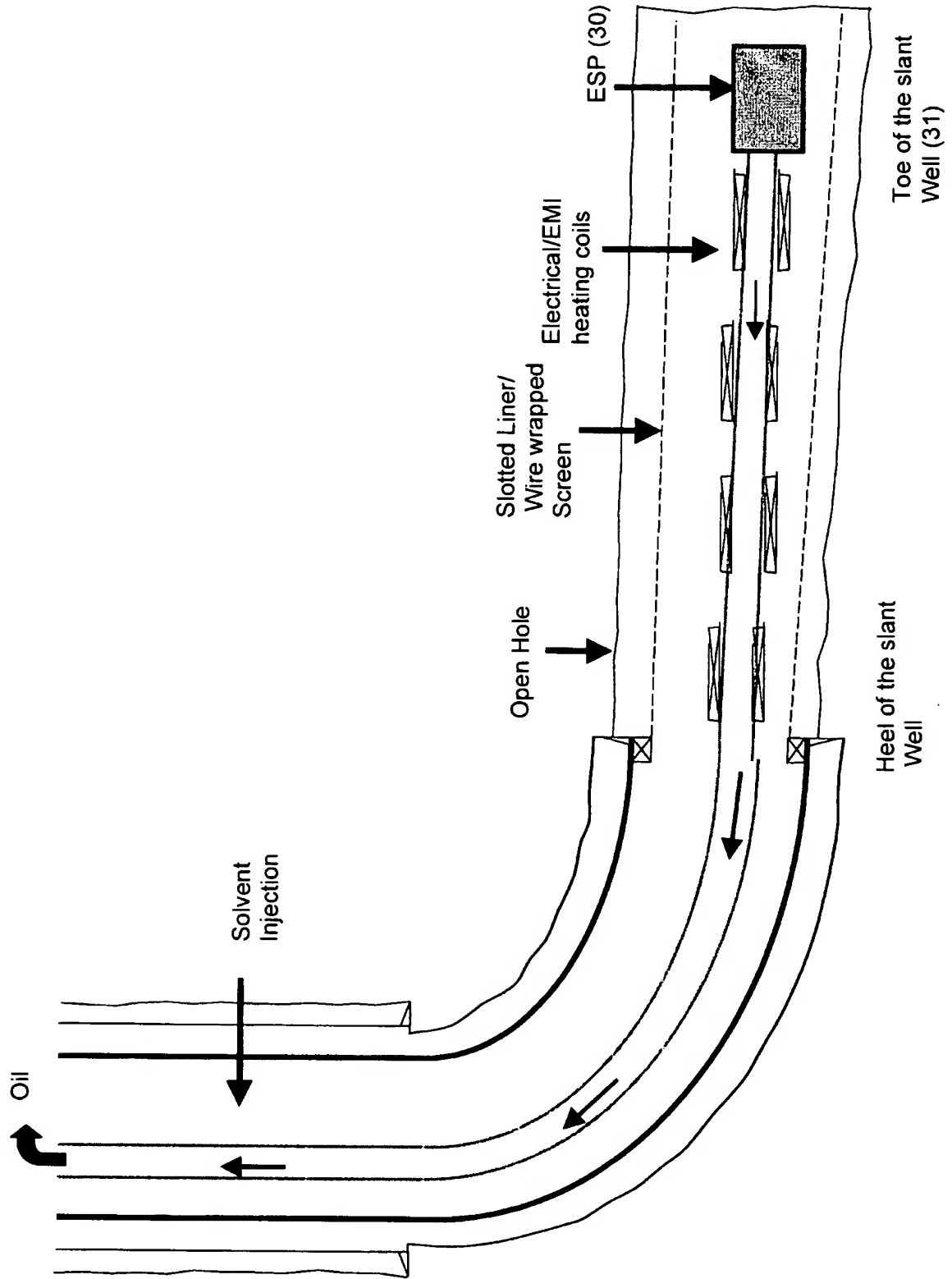


Figure 5

# SWEEP USING UP-DIP WELL

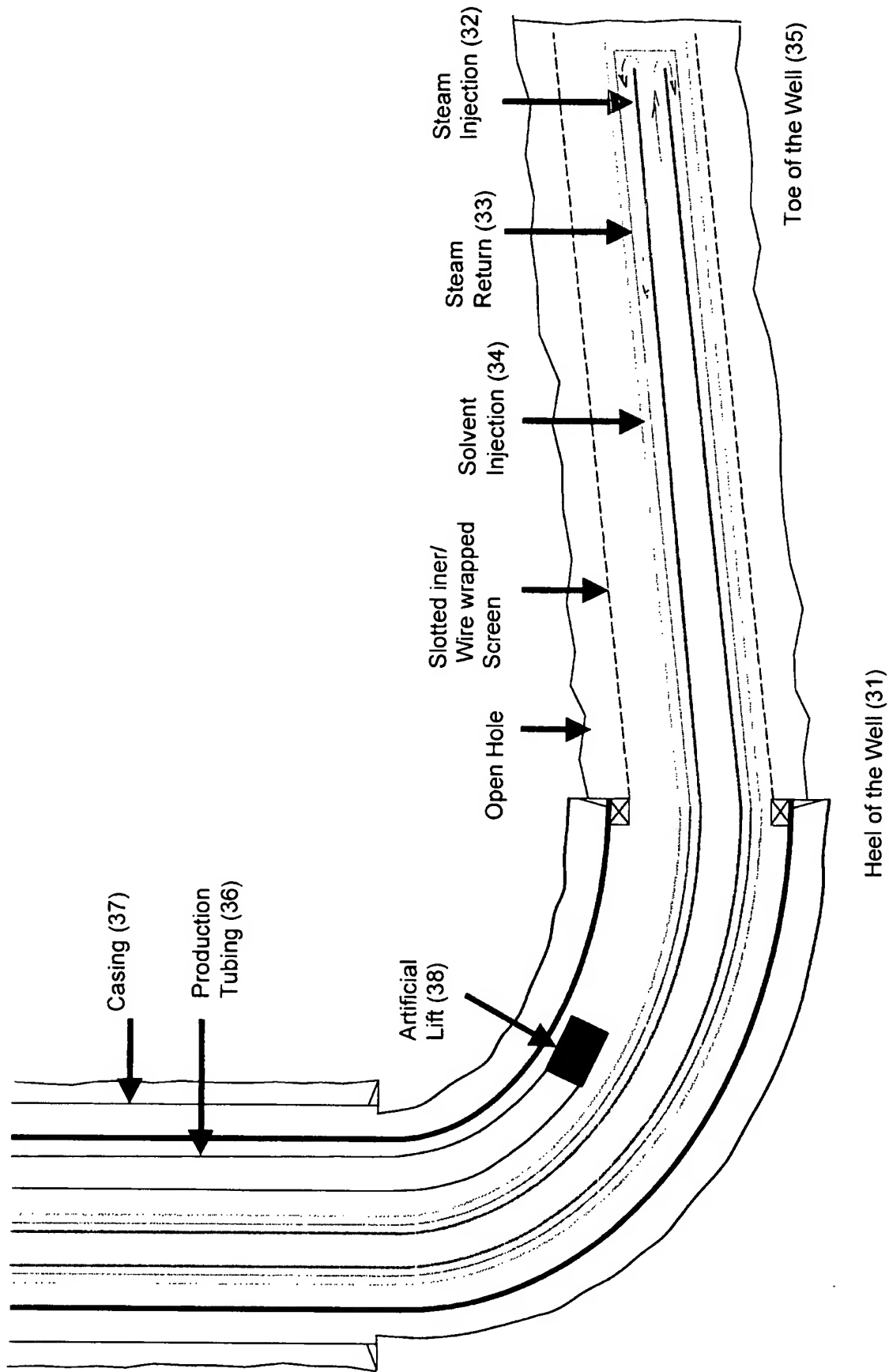


Figure 6

# SWEEP USING U WELL

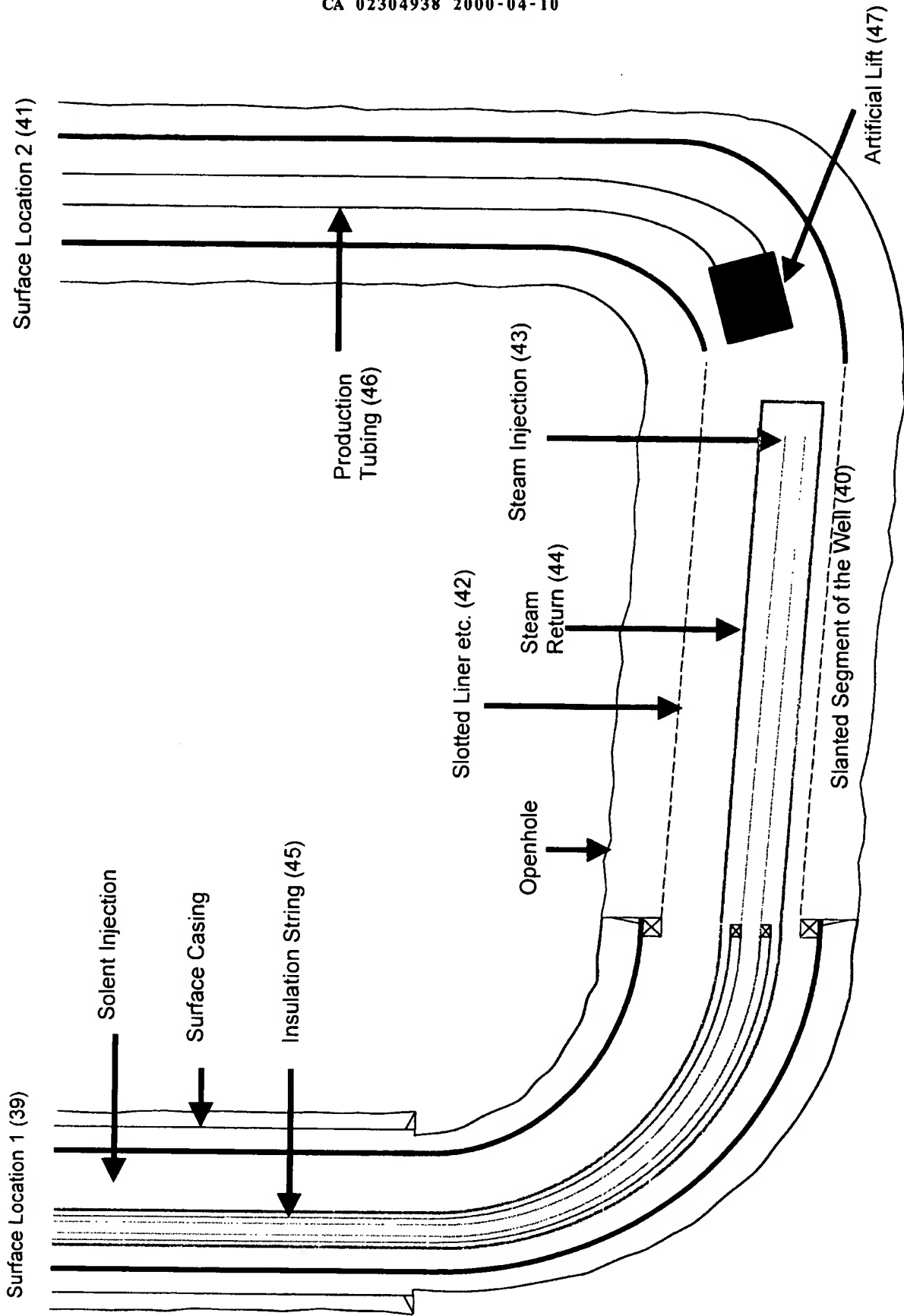


Figure 7